

**METHOD AND APPARATUS FOR ACHIEVING BROADBAND MATCHING OF
NARROW-BAND RESONATOR FILTER IMPEDANCES TO LOADS AND
SOURCES**

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METHOD AND APPARATUS FOR ACHIEVING BROADBAND MATCHING OF NARROW-BAND RESONATOR FILTER IMPEDANCES TO LOADS AND SOURCES

5 BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to matching the impedance presented by a narrow-band resonator filter to typical load and source impedances over a wide frequency range, and with particular application to broadband systems in which narrow-band filters internal to the system are required to provide matched impedances over the broadband frequency range of the system.

2. Background of the Related Art

15 A filter circuit typically presents an impedance that varies over frequency, with the impedance of the filter reaching an ideal or characteristic impedance in its pass-band. A band-pass circuit reaches its characteristic impedance at its "on-frequency" (f_c) in the pass-band, and presents drastically higher or lower impedance in the stop-band. Fig. 1a illustrates the transfer characteristic 10 of a band-pass filter and its f_c 12. Fig. 1b illustrates the impedance characteristics 14,16 presented by dual band-pass filter structures over the same frequency range, reaching an ideal impedance Z_0 18 at f_c 12. Figs. 2a and 2b both present low-pass filters that are duals of each other and their respective impedance characteristics reflect their dual nature. A topology that is a dual of another topology produces the same output transfer characteristic but typically one is a parallel structure whereas the other is a series structure. Complementary structures have output characteristics that are the inverse of one another.

Fig. 3a illustrates the well-known principle that maximum power is transferred to a load when the load impedance Z_L 26 and source impedance Z_0 24 match (i.e. they are equal for a resistive impedance, or the complex conjugate if the impedance is complex). Table 30 of

Fig. 3a illustrates the voltage and current values for the circuit **30** for when the filter is an open-circuit and a short-circuit (corresponding to the stop-band of the filter) and when the filter is at its characteristic impedance (corresponding to the pass-band). Given that these impedances are complex, the band-pass filter achieves maximum power transfer of the incident signal e_o **20** when the impedance of the filter $Z_L = Z_o^*$, where Z_o^* = the complex conjugate of Z_o . For the sake of simplicity, the table **30** illustrates the case where Z_o is resistive only (i.e. $Z_o = R_o$). **Fig. 3b** illustrates the power transfer of the circuit **30** as a function of the resistive impedance of the filter.

Fig. 4a is a conceptual illustration of a filter **42** driven by a source circuit **40** and driving a load circuit **46**. **Fig. 4b** is a conceptual illustration of the transfer characteristic **42c** of the filter **42**. For most applications, the existence of frequency components in the stop-band of the filter characteristic is not a significant problem. For broadband multichannel systems, however, the presence of significant out-of-band energy can present a real problem as a result of a mismatch in impedance in the stop-band between the filter and either the load or source. The power transfer will be less than optimal due to the mismatch, so out-of-band components having significant energy generated by either the source **40** and load **46** circuits can be reflected back, creating additional distortion in the system. Moreover, if the reflected signals are manifested as increased current or voltage, a source amplifier may clip or otherwise cause non-linear distortion of the signal provided to the filter **42**.

Figs. 5 illustrates an application where the impedance presented by a narrow-band filter can be problematic given the drastic difference between the impedance in the pass-band and the stop-band, and the wide frequency range over which the filter must operate. The circuit of **Fig. 5** is a structure common to frequency converters such as the one disclosed in the related application entitled "Agile Frequency Converter For Multichannel Systems Using IF-RF Level Exchange For Improved Noise Rejection," filed May 18, 2000 and which is incorporated herein in its entirety by this reference. This related application discloses a frequency converter for use in a broadband system that employs the circuit of **Fig. 5**. In such frequency converters, a mixer **56** is used in conjunction with a local oscillator signal **57** to

convert an IF signal to an RF signal. As described in the in the related application, generation of the IF signal requires that it be filtered through a band-pass filter 58, and that the mixing process can produce additional unwanted distortion signals in the RF output signal. The output of filter 58 is coupled to ports of the mixer. Because the mixer is a passive balanced device, signals are generated at all ports that may contain various components of the input signals. These "leakage" signals that can appear at the output coupled to filter 58 likely will be out-of-band for the filter 58. Thus, if the impedance of filter 58 as seen at the port of mixer 56 is significantly mismatched to the impedance of mixer 56 in the stop-band of filter 58, a significant percentage of the power of the incident out-of-band leakage signals will be reflected back into the mixer and will show up in the RF output signal. It should be noted that for other applications, narrow-band filtering might be required for the other ports of mixer 56 as well, making impedance matching of the filters even more critical.

One technique commonly used in the art to match the impedance of a filter over an entire range of operation is a diplexor circuit that is conceptually illustrated in Fig. 6a. This circuit provides a structure that is the exact complement 62 of the band-pass filter 60, such that the impedance seen by the input signal is the source impedance over the entire frequency range, as illustrated by Fig. 6b. It is extremely difficult if not impossible, however, to build a structure complementary to tuned resonator filter circuits in accordance with the diplexor structure of Fig. 6a. Thus, this solution works for filters that are not resonators, but does not work for resonator circuits that are advantageously used internally to broadband frequency applications.

Several improved narrow-band tuned resonator filter circuits for broadband applications are disclosed in related applications entitled "Magnetically Coupled Resonators For Achieving Low Cost Band-Pass Filters Having High Selectivity, Low Insertion Loss And Improved Out-Of Band Rejection," filed March 16, 1998 having U.S. Serial No. 09/039,988 and Low Cost, Narrow Band-Pass Tuned Resonator Filter Topologies Having High Selectivity, Low Insertion Loss And Improved Out-Of Band Rejection Over Extended Frequency Ranges, filed September 29, 1999 having U.S. Serial No. 09/408,826, both of

which are incorporated herein in their entirety by this reference.

While there have been some attempts to provide better impedance matching between tuned resonator filters and the devices to which they are coupled, no prior art method or apparatus has been able to provide sufficient matching, particularly at or near the on-frequency of the filter, such that frequencies of IF very close to the frequency of L_O such as in the context of the mixing process of **Fig. 5**.

Therefore, those of skill in the art will recognize that there is a need for a method and apparatus by which the characteristic impedance of narrow-band resonator filters can be matched to the load or source impedance of the structures to which they are coupled over a broad range of frequencies, particularly for application to broadband multichannel systems.

SUMMARY OF THE INVENTION

It is one objective of the method and apparatus of the present invention to provide impedance matching between tuned resonator filters and the devices to which they are coupled over the frequency range of broadband multichannel systems.

It is further an objective of the present invention to provide sufficient matching to prevent leakage of other input signals such as local oscillator and converted RF signals to be reflected back into a mixer during up-conversion in broadband multichannel systems that can cause degradation in the distortion performance of the system.

In accordance with the present invention, the foregoing and other objectives are achieved by a novel and non-obvious method and apparatus by which the characteristic impedance of a tuned resonator filter can be matched to the impedance of those source and load devices to which it is coupled, and particularly to the ports of a passive mixer.

A first tuned resonator filter is isolated from the port to which it is coupled using a series resonator circuit having a characteristic that is sufficiently a dual of the transfer function of the resonator filter. The series resonator is an open circuit for the stop-band of the tuned resonator filter, and a short circuit in the pass-band of the resonator filter. Thus, to the port, the tuned resonator filter appears as a match to the impedance of its source in the pass-band, and an open-circuit in the stop-band. The port is further coupled to a second tuned resonator filter through an isolation resistor. The second tuned resonator filter is either an exact duplicate of the first tuned resonator filter, or has a similar enough transfer characteristic to the first tuned resonator filter that the impedance seen at the port for frequencies close to the on-frequency of the first filter is not unacceptably degraded.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method and apparatus of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

Figure 1a illustrates an output transfer characteristic of a band-pass filter.

Figure 1b illustrates the impedance characteristic of a band-pass filter.

Figure 2a illustrates the impedance characteristics of a low-pass filter.

Figure 2b illustrates the impedance characteristic of a high-pass filter.

Figure 3a illustrates power transfer of a signal as a function of the load impedance.

Figure 3b illustrates the power transfer characteristic of a band-pass filter as a function of its characteristic impedance.

Figure 4a is a conceptual representation of a band-pass filter with a source circuit driving its input port and a load circuit coupled to its output port.

Figure 4b is a conceptual representation of the output transfer characteristic of a band-pass filter with frequency components in its stop-band.

Figure 5 is a conceptual illustration of an application where narrow-band filters are used in a broadband system during up-conversion of IF signals to RF channel frequencies and where a matched impedance is important to prevent reflection of leakage signals generated by a mixer.

Figure 6a is a conceptual illustration of a diplexer of the prior art.

Figure 6b is a conceptual representation of the impedance seen at the input of the diplexer as a function of frequency.

5 **Figure 7a** is one preferred embodiment of the impedance matching circuit of the present invention.

Figure 7b is an equivalent circuit for the pass-band of the resonator filter the impedance of which is to match the desired impedance.

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Figure 7c is an equivalent circuit for the stop-band of the resonator filter the impedance of which is to match the desired impedance.

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Figure 7d is a representation of the impedance characteristic of the embodiment of Fig. 7a.

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Figure 8a is a preferred embodiment of the impedance matching circuit of the present invention illustrating one of many resonator filter implementations for which the impedance matching circuit may be employed.

Figure 8b is a representation of the impedance characteristic of the embodiment of Fig. 8a, illustrating the result of increasing the value of the isolation resistor.

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Figure 9a is a preferred embodiment of the impedance matching circuit of the present invention illustrating how the second resonator may be truncated and simplified if the application can tolerate the resulting degraded impedance matching in the pass-band of the resonator filter.

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Figure 9b is an equivalent circuit for the pass-band of the resonator filter of Fig. 9a the impedance of which is to match the desired impedance.

Figure 9d is a representation of the impedance characteristic of the embodiment of Fig. 9a, illustrating the result of truncating the second resonator of Fig. 9a.

DETAILED DESCRIPTION OF THE INVENTION

As previously discussed it is critical in certain broadband system applications that narrow-band filters present a well-matched impedance to source and/or load over the entire frequency range of the system. One prior art solution to maintaining constant impedance for a filter for non-resonator band-pass filters is to couple a complimentary band-stop filter to the band-pass filter. Creating a complimentary structure for a band-pass resonator filter, however, presents a fundamental problem.

The method and apparatus of the present invention is now described with reference to Figs. 7a through 9b. Fig. 7a illustrates the concept of the invention from the perspective of the output port 84 of a first band-pass resonator filter 72, which is coupled to a load (typically 50 or 75 ohms), for example, a passive mixer 56. R_O 70 represents a typical impedance of a source providing input voltage e_i 71 (typically 50 or 75 ohms) to which the output impedance of filter 72 is preferably matched. The series resonator formed by L_I 74 and C_I 76 is designed to have a transfer function that is roughly a dual of resonator filter 72 such that the series resonator becomes a short-circuit in the pass-band of resonator filter 72, and an open circuit in the stop-band of filter 72. In one preferred embodiment of the invention, a second band-pass resonator filter 80 is coupled to port 84 (through isolation resistor R_I 78) that is identical to the resonator filter 72 in structure and transfer characteristic. Both resonator filters have a parallel (shunt) structure and are therefore short-circuits in the stop-band, and are "on" and thus couple source and load impedances to their outputs in the pass-band. Resonator 82 is terminated to ground with a load resistor that is equal to R_O 70.

Fig. 7b illustrates the equivalent circuit for frequencies in the pass-band, and Fig. 7c illustrates the equivalent circuit for frequencies in the stop-band of the two resonator filters. If isolation resistor R_I 78 is equal to R_O 70, then the impedance seen at port 84 is $2R_O/3$ in the pass-band, and R_O in the stop-band. The impedance characteristic of the circuit of Fig. 7a is illustrated in Fig. 7d. It can be seen that the impedance is not perfectly matched throughout

the entire frequency range, with some insertion loss in the pass-band. Notwithstanding, this a considerable improvement. The insertion loss can be compensated by increasing the value of R_1 78 at the expense of increased impedance in the stop-band.

5 **Fig. 8a** illustrates an implementation of the present invention using one of the parallel resonator topologies disclosed in the aforementioned '988 and '726 related applications. Mixer 56 is coupled to port 84 for illustration purposes. The impedance characteristic of the circuit illustrated in **Fig. 8b** contemplates that isolation resistor R_1 78 is chosen to be greater than the value of R_O 70 to compensate for the insertion loss experienced in the pass-band.

10 **Fig. 9** illustrates an alternate preferred embodiment that is somewhat simpler and can be employed when there is not significant energy in the frequencies around the on-frequency of the resonator filter 72. The resonator filter 72 is the same as in **Fig. 8a**, but the resonator 80a has been truncated to only one resonator, rather than two in parallel. Although the
 15 characteristic of the resonator 80a will no longer be as sharp as that of resonator filter 72, it is good enough provided the resulting relaxed matching does not create problems for signals in the frequency for which matching has been degraded. **Figs. 9b** and **9c** illustrate the equivalent circuits for the circuit of **Fig. 9a** in the pass-band and stop-band respectively of the resonator filter 72. The difference between the circuits of **Figs. 8a** and **9a** is that 80a is no
 20 longer terminated, and is replaced by a resistance R_{P-loss} 88 that represents the resistive loss while resonator 80a is resonating. Provided there are no significant components falling within the frequency ranges 90, the degraded impedance matching occurring as a result of the simplification in resonator 80a.

25 The embodiments disclosed herein are for illustrative purposes, and those of skill in the art will recognize that other applications requiring matched filter impedance over a wide range of frequency and other topologies of tuned resonator filters may be used in substitution for those disclosed herein without departing from the intended scope of the invention.